DESIGN AND ANALYSIS OF INTAKE SYSTEM FOR FSAE VEHICLE

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Abstract -*A throttle valve is one of the main components of the intake system of a vehicle and is used to control the air flow rate into the combustion chamber at different engine speeds. Consequently, it has considerable effect on the engine power and performance especially at high engine speeds. The butterfly throttle valve is more common in commercial vehicles due to its simplicity. However, the butterfly throttle plate may affect the engine performance by incurring some pumping losses at high engine speeds even with the plate at wide open throttle (WOT) position. Hence it is proposed in this research work to replace and compare the performance of a spark ignition engine butterfly throttle valve to a newly designed barrel-shaped one with regards to the induced air mass flow rate. The main benefit of the proposed barrel-shaped throttle valve is the elimination of the flow restriction at WOT and high engine speeds.*
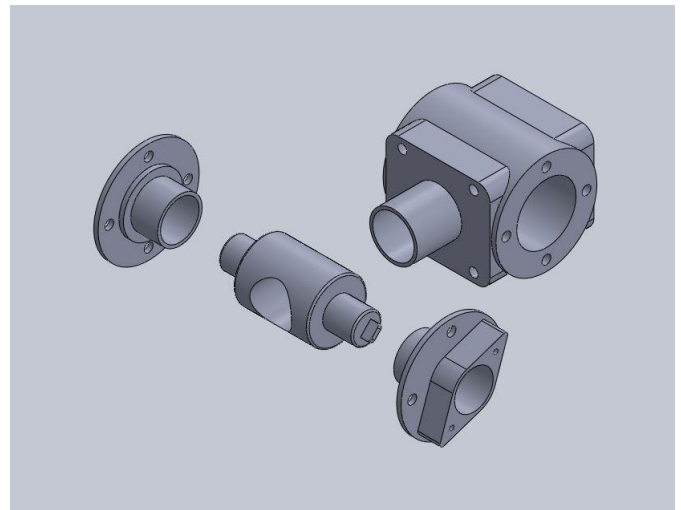
Key Words: FSAE, Barrel valve throttle body, restrictor, plenum, intake runner.

1. INTRODUCTION

Acoustical tuning of intake manifolds is a common practice used to achieve gains in volumetric efficiency in a pre-determined region on the torque curve. Acoustic modelling of unsteady air flow into internal combustion engines provides an opportunity to maximize torque output at a pre-determined operating speed or to increase torque over a pre-determined speed range. By designing a system to resonate at specific frequencies, a greater charge of air can be packed into the combustion chamber, increasing the volumetric efficiency of the engine, resulting in these performance gains. The runner length is defined as the length of the flow channel which extends from the intake port on the head to the point at which the individual runners branch out from a manifold, or plenum. Throttling is an important part of the intake system, the throttle body is usually positioned between the air filter and the intake manifold. Its main objective is to control the amount of air flowing into the engine combustion chambers.

Fig-1: 3D model of Barrel valve Throttle Body

1.1. Literature Review

Ashraf W, Khedr S, Diab A, and Elzaabalawy H, "Effect of Replacement of Butterfly Throttle Body by Barrel Throttle Body on Mass Flow Rate using CFD".
In this paper we found the various effects on both the throttle body. We also got to know about components of barrel and butterfly throttle body.

Cauchi J, Farrugia M, and Balzan N, "Engine Simulation of a Restricted FSAE Engine, Focusing on Restrictor Modelling".
In this paper we studied about the engine simulation and its calculations. We also got some reference for designing of our model.

Zimmerman S, Cordon D, Anderson M, and Beyerlein, S, "Development and Validation of an Impedance Transform Model for High Speed Engines".
In this paper we studied how a new intake tuning model has been developed using an Impedance transform Model along with a minimal set of limiting assumptions.

Byam B, Fsadni J, Hart A, and Lanczynski R, "An Experimental approach to design, build and test a throttle body and restrictor system for formula sae racing.
In this paper we studied about the throttle body and restrictor. So, designing and manufacturing of the restrictor and throttle body was crucial. We took input data like designing parameters, assumptions in calculations and also manufacturing guidelines from this paper.

2. PROBLEM STATEMENT

1. A crucial element in running a racing car is throttling the engine. However, at wide open throttle, any flow obstruction increases pumping losses and is therefore undesirable. This makes a throttle valve with minimum flow restriction at wide open throttle quite appealing.
2. Another important parameter in intake design is the pressure drop in the engine manifold. Pressure drop in intake manifold has a negative impact on the engine efficiency and power density.
3. Dimensions of plenum and its volume are a parameter which cannot be neglected. If the plenum volume is too large, the throttle response will decrease and a small plenum volume will starve the engine of air.
4. Dimensions of the runner are important as the pressure wave will make its way through the port before the valve shuts again, when the next wave is created.

3. THEORY

An internal combustion engine always requires air and fuel to produce work. Improved breathing will almost always improve the combustion in an engine. Air, like all gases, is compressible, or elastic, which means resonance will exist. In this study we will exploit this property of air to increase the charge of air entering the combustion chamber. It is not uncommon to find that a better air supply may actually reduce peak pressure at a given power level.

When something moves or vibrates to produce sound, the vibration is transmitted to the air in immediate contact with the moving medium. The simplest vibratory motion, known as 'Simple Harmonic Motion',

is closely approached by the action of an ordinary tuning fork. Its mechanical counterweight is the pendulum's bob weight swinging at constant time intervals alternately to left and right of the central position.

To understand this, we should understand the basic theory of sound and its relation to what occurs in engine pipe systems. Consider the pendulum is swinging or vibrating over a certain distance, displacement, or amplitude on either side of the mean position. Movements to one side are positive, those to the other side are negative. If the variation of 'swing' over a period of time is plotted graphically, a sine curve is the result. By this we can define Simple Harmonic Motion by the equation –

$$y = a \sin 2\pi t/t$$

Where, y is the displacement and a and T are constants. A complete swing from positive to negative positioning is known as a cycle.
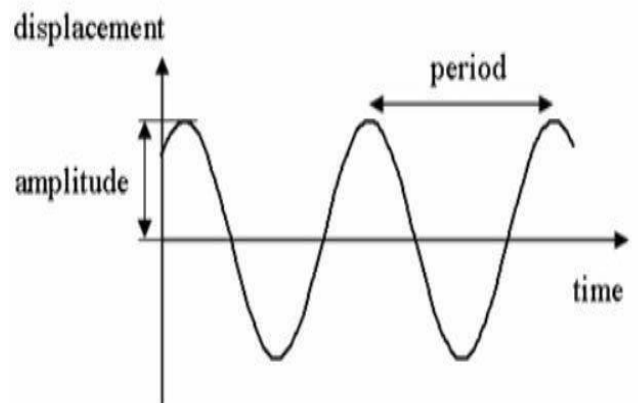

Fig-2: Basic Illustration of Simple Harmonic Motion

●The amplitude a represents the maximum distance on either side of the mean position. The amplitude in the equation is constant.
●The other constant T is the time period taken by one complete cycle.
●If the number of cycles per second or frequency is f, we then have

$$f = 1/T$$

4. DESIGN, CALCULATIONS AND SIMULATION

KTM Duke 390 engine is selected for this study. The analysis is divided into three parts

1. Pre-processor: Wave Build
2. Solver: Wave
3. Post-processor: Wave Post

4.1. Designing Wave Build Models

There are two major parts; the first is to design the complete engine system and then adding the custom built components in the engine system for tests related to measuring engine power and torque.

For simulating any component related to the engine, its model has to be built in Wave Build. Wave Build is used as a pre-processor for Wave analysis. It is the primary step in every simulation. Here, all the parameters required to build the engine system, like operating conditions, intake system (throttle body, plenum runner, fuel injector), engine parameters (bore, stroke, valve timings, port lengths) exhaust system (exhaust header lengths, muffler) are given as input to accurately simulate the required scenario.

4.2. Simulation

The procedure adopted for the simulation of engine using Ricardo Wave Build.
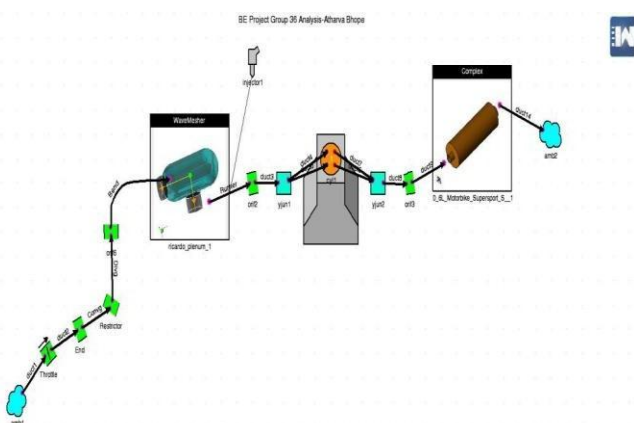

Fig-3: Engine model in Ricardo WaveBuild

This is the engine model created on Wave and the command prompt shows the solution obtained on solving the model at various engine speeds. Wave automatically creates requested plots at the end of each simulation. The model at this stage is ready to run through an input check and was set to create the requested data for post-processing.

4.3. Design of Restrictor

The intake manifolds which are used in Formula Student competitions uses a unique Throttle Body-Restrictor-Plenum design. The major challenge while incorporating this design is the air flow restriction caused by the 20mm restrictor. So the restrictor in a Formula Student vehicle is critical to engine performance. The restrictor is design by considering that when a fluid flows through a duct with no work or heat transfer, the only factors which can cause a change in fluid properties are: a change in flow area, and frictional forces.

For the calculated Maximum Mass Flow Rate of 0.0703 kg/s, the Delta Pressure (Inlet Pressure – Outlet Pressure) was calculated for different converging and diverging angles. The minimum angle that can be manufactured with considerable precision was estimated at 4 degrees, hence the diverging angle has been considered from 4 degrees. The Diverging angle range was considered until 20 degrees because the value of Delta Pressure was increasing abruptly after 15 degrees, clearly visible by the lack of any minimum value in the 20 degrees columns. The Converging Angles have been considered from 10 degrees referring to the estimates of various Venturi designs.

XX,XXX	Min Value in Row / Min Value in Column	Diverging Angles						
		4	6	8	10	12	15	20
Converging Angles	10	20000	19398	19504	21486	22032	20044	23033
	12	19948	19700	19326	19679	19960	19882	23846
	14	22249	19621	20619	20576	21336	19585	21844
	15	19274	18443	21242	19601	20919	19686	22292
	16	21203	20240	20654	20835	19242	20095	24341
	18	19556	18204	20671	21604	22123	22906	20630
	20	20318	18523	20263	24719	22180	21233	24019

Fig 4. Converging and Diverging angles

Hence to smooth out the flow and to obtain a minimum pressure loss we chose converging angle of

18 degrees and diverging angle of 6 deg. Longer diffusers with lower exit approach angles produced more airflow at lower pressure drops because of effects of airflow separation. This results in a laminar flow which is necessary in the intake manifold. For this reason we chose the diverging part to be 148mm.
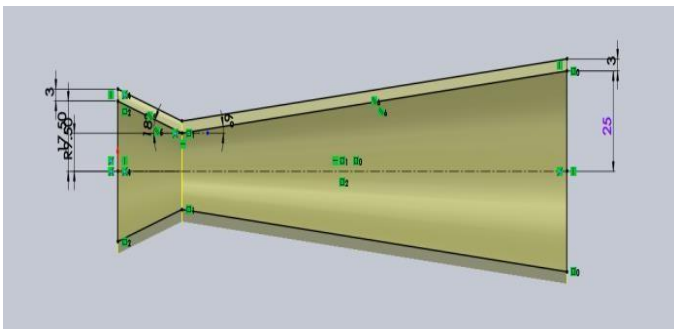

Fig-5: Design of restrictor

4.4. Design of plenum

The plenum area is where the intake runners meet. The plenum volume is a very importing tuning aid. As high velocity gasses flow through the throttle body, the plenum give the gasses a chance to slow down, as the velocity is reduced the pressure rises. Higher pressure means that the air will be denser, and of course that means more power. As rpm goes up you need a larger plenum, but a larger plenum will reduce throttle response and low-end power. A plenum also reduces peak air velocity through the throttle body. The plenum volume of the vehicle is 933cc which is 2.5 times larger than the volume of the engine. This helps us in giving a high end power to us. The shaped of the plenum considered was a cylinder with hemispherical ends as it was easy to manufacture, has a volume efficient shape and as the plenum generates substantial vacuum inside it, which goes on increasing as the engine speed increases, cylindrical shape can sustain the high pressure without buckling as they do not have any corners, as stress concentrations are more at corners.
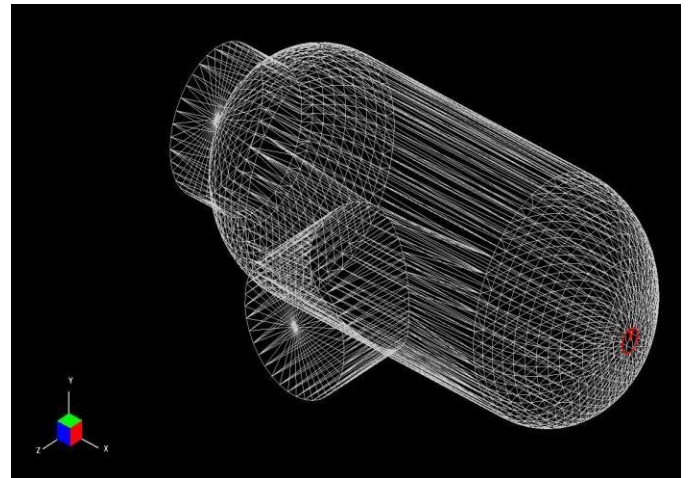

Fig-6: Plenum mesh

4.5. Design of Intake runners

Improved breathing will almost always improve the combustion in an engine. It is not uncommon to find that a better air supply may actually reduce peak pressure at a given power level. The fact that air, like all gases, is compressible, or elastic, means that resonances will exist.
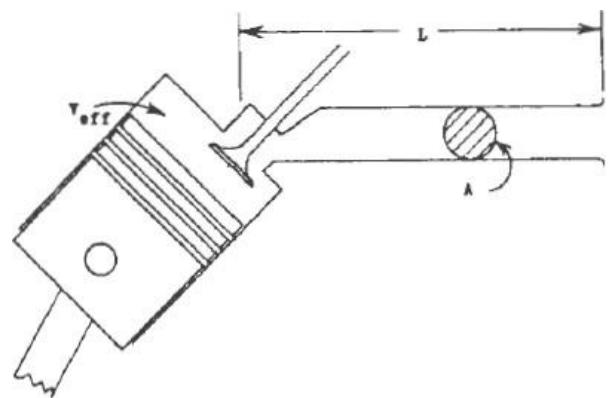

Fig-7: Cylinder and Intake Pipe modelled as Helmholtz Resonator

5. RESULT AND DISCUSSION

The construction of a simulation engine for race and the tests to find optimum runner length, plenum volume and the impact of high discharge coefficient provided a good fundamental of how the engine is affected by individual geometry. Since longer runner are preferable if the engine speed range of peak

power are below 9000 rpm and shorter runner length are preferable if the peak power are for higher rpm the optimum runner length for this particular engine that during competition are mostly driven between 7000 – 11000 rpm is 217mm. The benchmark length of 200mm runner length is an acceptable compromise between high powers over driving rpm range. Assuming 100% volumetric efficiency it may take some amount of time before the engine actually start starving on air and drops in rpm. This can result in a significant loss in throttle response and hence drivability. Unfortunately the reverse applies for open throttle as well. During race condition it is essential that there is power immediately.

6. CONCLUSION

The results obtained after the simulation show that the graph of various parameters of engine vs the engine speed. The data show that the value of peak torque with the restricted KTM 390 engine is 37 N-m, which is higher than the value obtained with an unrestricted KTM Duke 390 engine which is 35 N-m. Also the peak power developed by the restricted engine is 35 kW which is 47 hp, this is also greater than the value of peak power obtained with an unrestricted engine which is 43 hp.
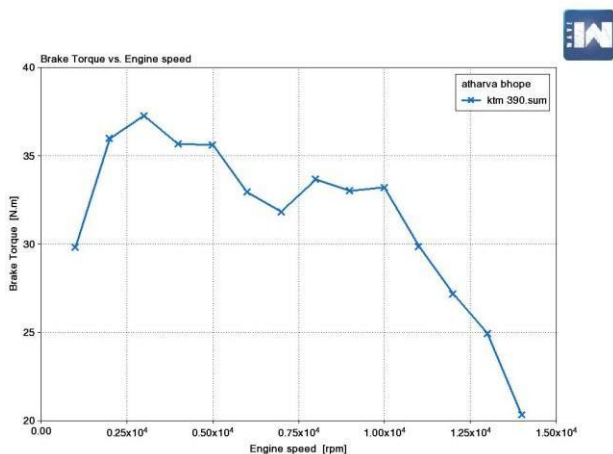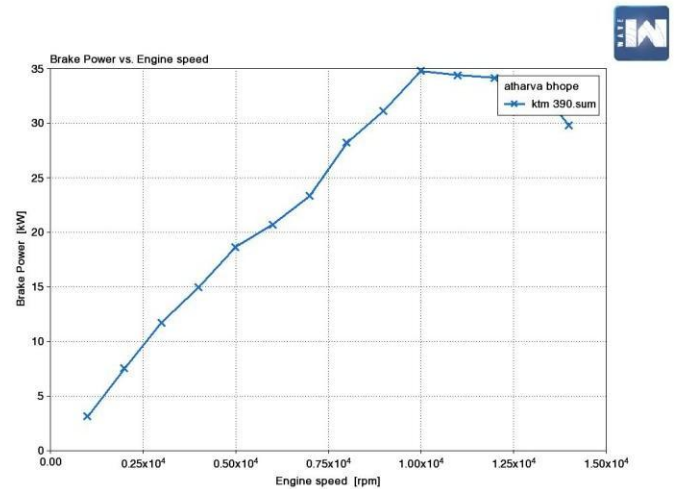

Fig-8: Brake Torque vs Engine Speed

Fig-9: Brake Power vs Engine Speed

7. REFERENCES

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